NOTES ON EROSIONAL PROCESSES AND STREAM GRAVELS.

By Frank A. Craft, B.Sc., Linnean Macleay Fellow of the Society in Geography.

(One Text-figure.)

[Read 31st August, 1932.]

Introduction.

It was found impracticable to include the material of these sections within the compass of regional papers, so they have been grouped for convenience under a common heading. The four parts may be stated briefly as follows:

i. *Land Forms in Granite Areas.*—A stream system working down on to granite will induce mature land forms therein while surrounding rocks remain at higher levels, and an increase in relief following the revival of streams flowing over a granite peneplain will result in an increased rate and depth of weathering.

ii. *Differential Erosion in Horizontal Rocks.*—The rules governing the widening of valleys in the horizontal rocks of the Blue Mountain plateau are examined, and the conclusion reached that the existing broad valleys were cut when their lowest points were not far above sea-level.

iii. *The Material carried by certain Highland Streams.*—The conditions for shaping ellipsoidal and flattened stream gravels are determined in terms of the power and behaviour of transporting streams, and it is suggested that there are limiting conditions for the attainment of maximum pebble size in any stream.

iv. *Surface Deposits and past Climates in the Shoalhaven Valley.*—Tertiary drifts in this area accumulated under conditions of mild storminess or of uniform rain, and recent gravel deposits in the valleys were due to erosion of a landscape which was inadequately protected by vegetation at the time of the most recent Kosciusko glaciation.

i. *Land Forms in Granite Areas.*

The topography of granite areas has received some attention from Australian physiographers: thus Marks (1912) described parts of the Burdekin valley in which granites take on lower and more rounded forms than the neighbouring rocks, but Browne (1928) stated that—(although) "we often see granite making the uplands, with rocks of inferior resistance forming the valleys and lowlands, occasionally the reverse is found, granite being at the lower level". He concluded that the phenomena were "independent of the age or the relative inherent resistances of the rocks concerned to mechanical erosion", that the topography in which granite forms the uplands may be regarded as normal, while its presence as lowlands may be due to cleavage, original position and extent, or to the effects of "antecedent deep weathering". Sussmilch (1931) inclined to the opinion that the Bathurst granite is a strong formation, while Andrews (1904) noted that the siliceous granites of New England form the majority of the highest points in that region.

Thus there has been a tendency to stress the effect of rock type and structure on topography in such cases, but it also appears that the presence and development of streams have had a considerable effect on the final surface in granite areas, of which the uniform Braidwood-Araluen mass may be used as an example. In general, its weathered surface forms part of an undulating plain between 2,100 and 2,400 feet above sea-level, but residuals and terraces in the Shoalhaven Valley to the south-west of Braidwood rise to 3,000 feet, and elsewhere the wide, flat-bottomed valley of Araluen Creek has been eroded to less than 500 feet above sea-level. East of Braidwood a narrow belt of granite crosses the Mongarlowe-Shoalhaven dividing ridge at 2,900 feet and comes to the general level of that feature, although a few miles to the north weak and fissile Ordovician slates rise above the deeply weathered granite plains, the control in that instance being chemical weathering. These facts suggest that a well developed stream system finds granite to be no great obstacle to its downcutting, and it may develop wide valleys or plains while neighbouring sediments of inferior mechanical resistance are left at higher levels. Marks's examples in the Burdekin valley, the granite peneplain in the Tuross-Umaralla area to the east of Cooma, and the middle valleys of Cox's River are all low-lying parts occupied by numerous streams which originated, in general, on sedimentary or metamorphic rocks above the original level of the granites themselves. On the other hand, the higher ridges to the west of the Murrumbidgee River between Cooma and the Cotter junction (Browne, 1928) and those of north-eastern New England (Andrews, 1904) appear to be long-established divides, and the streams have avoided them in favour of consequent slopes or special lines of weakness, leaving the granite ridges virtually free from some of the most destructive forces of chemical weathering, and thus liable only to a slow reduction. Very rapid erosion of neighbouring rocks in the first place is the essential condition for this action, and the small area of granite surviving as peaks in most districts shows that, as a rule, Browne's conclusion as to their normal behaviour is scarcely established.

The Bathurst district provides an interesting series of problems. It is a hollow between higher tablelands to the east and west, and has been described as a senkungsfeld (or downfaulted block) by Andrews (1910) and by Sussmilch (1931). It is likely that a downwarp formed the original eastern margin of the hollow, but Sussmilch notes that the edge of the senkungsfeld coincides approximately with the edge of the granite comprising it (p. 82), a fact that seems to bear a definite relationship to the course of the Macquarie River along the greatest elongation of the mass. Craft (1928, p. 224) noted the widening of the tributary valley of Solitary Creek when it passes on to the Bathurst granite, and Browne (1928) shows a distinct rise in the same locality as the granites of the valley floor give place to the sedimentary rocks of the uplands. Thus the Bathurst "senkungsfeld" may be of erosional and not of tectonic origin, and its lowering was probably due to a well developed stream system giving conditions favourable for greater weathering and erosion in the granites than in the enclosing sedimentary and metamorphic rocks, as in the similar case of Araluen Valley. The hill scarps marking the passage from higher to lower land resemble many of the residual ridges in the Goulburn and Marulan districts, such as Mts. Towrang and Vessey, which lie on the edges of other granitic intrusions, and the appearance of the Bathurst features when viewed from below is reminiscent of ridge lines in the Shoalhaven Valley of the Braidwood district, which are not due to faulting. It is unwise to call the Bathurst slopes "fault scarps" on appearances which are typical of unfaulted areas.

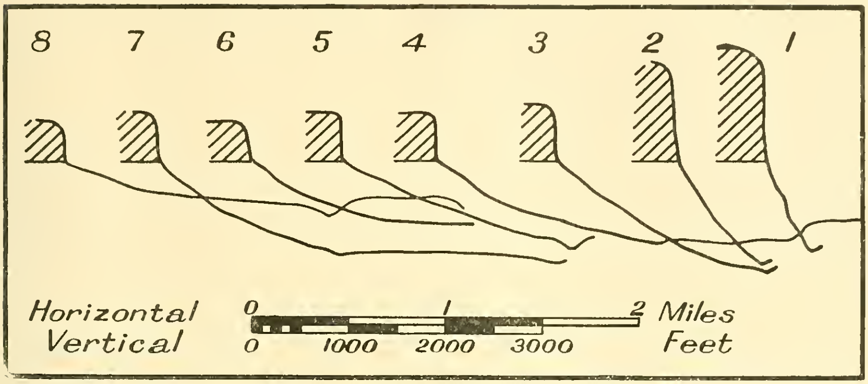
The question of surface weathering is also important: W. R. Browne believes that weathering of granites on a peneplain surface may proceed to such an extent and to such a depth that stream revival will result in the rapid erosion of wide, mature-looking valleys—an idea whose application to Bathurst finds no favour with Sussmilch. The present writer believes that maximum weathering often occurs under conditions of some relief; thus the granite plains near Tallong show tors and rocky slopes, while the mature country near Braidwood and about the head of Tuross River has similar outcrops on the ridges and slopes, although alluviated valleys in those places are smooth, and the surface existed in its present form before the close of the Tertiary period. As a contrast, many of the steep ridges falling to the Pleistocene Araluen Valley are deeply weathered in places where it is not possible for talus to come, and they have reached a state similar to that described for the Bathurst area, or parts of the Cox valley east of Hampton. It seems that weathering is accelerated by increase in relief due to stream revival, probably because of the increased freedom of circulation enjoyed by the groundwater, and deep weathering of ridges and slopes is accompanied by the deposition of alluvium in the valleys. It follows that such conditions are not a reliable indication of ancient landscapes or of prolonged peneplanation, as has been suggested for the Bathurst area.

ii. *Differential Erosion in Horizontal Rocks.*

It is well known that soft rocks overlying a highly resistant formation can be shaped into a mature landscape by erosive forces using the upper surface of the more resistant strata as a base-level of erosion, but there seems to be some confusion regarding the process of valley formation in an area of horizontal rocks where the capping is the most resistant feature. The term "benching" has been used locally to indicate the process of erosion in this case and the production of flat-bottomed valleys, but it is unsatisfactory in use and associations: thus one writer mentions "bluff, wall-like benching", and another speaks of "benching high above base-level" in a similar connection, the terminology in both cases being at fault.

An examination of valleys in the Blue Mountain area where soft Permian rocks are exposed under an impervious, resistant capping of Triassic sandstones, discloses that valley widening is associated with the retreat of both the crowning precipices and the talus slopes, although the latter tend to become more gentle as the process develops (Text-fig. 1). Here the principal work is the undermining of the sandstones so that pieces will split off along vertical joint planes and fall into the valley beneath: this is accomplished by oversteepening of the soft rock surfaces immediately below the precipices by normal erosion, and the unstable slopes thus formed give way in the course of time, and bring down sections of the precipices. The process is assisted by wind erosion at the base of the hard rocks, but the nature of the capping practically inhibits the action of other normal forces of erosion and weathering.

As the thickness of soft rock exposed decreases when compared with that of the resistant capping, the rate of widening tends to decrease, and to be more dependent on wind action. This is shown by the prevalence of caves under such circumstances immediately below the hard rocks, and by the rounding of the top edges of the precipices, which are also carved into monuments by the combined forces of wind and rain. In some instances the convex weathering slope thus induced may extend downward almost to the base of the original precipice, and



Text-fig. 1.—Profiles of valleys developed in essentially horizontal rocks; the shaded portions represent hard Triassic sandstones which are underlain by softer material. They are taken (with the exceptions noted) perpendicular to cliff lines and streams where these are parallel, and there are no considerable tributaries. Nos. 1 and 3 are each 4 miles above the point where the base of the resistant sandstone comes down to river level on their respective streams, and as the rocks are similar, they are directly comparable. Higher terraces on the valley floors show the effect of hard layers of sandstone, and the shorter members each represent half of a symmetrical valley. Nos. 1 and 2 are after Carne's "Western Coalfield", whose sections include many profiles of such valleys of varying depth, in each case the slope of the talus being of the order of 10° when the valley floor is enlarging laterally, as in Nos. 4 to 7. Localities: 1.—Grose River at Mt. Caley, with basalt capping; 2.—Grose River at Blackheath; 3.—Wollondilly River, E. side, ¾-mile above Cox's River; 4.—Narrow Neck, Katoomba, and Megalong Valley to NW; 5.—Megalong Valley, Katoomba, a SW line; 6.—Blackheath Glen, Medlow Bath; 7.—Jamieson's Creek, with the tributary valley of Reedy Creek flattening the lower part; 8.—Narrow Neck, Katoomba, and the divide between Megalong and Galong Creeks, Megalong Valley. Height above sea-level is variable. Vertical exaggeration = 2·64.

then the widening of the valley depends on the wearing away of the hard capping, assisted to a minor extent by the sapping action already referred to. In all cases the overlying strata have a definite protective effect on the soft rocks, although these latter constitute a zone of weakness, and the final rate of valley widening lies somewhere between the rate in the hard rocks and that in the softer if each were freely exposed, and it tends to decrease as the valley becomes wider. The effect of competent tributaries will be readily appreciated, as the valley formed along each tends to become not much inferior to that of the main stream, but where tributaries are missing or where erosion is approaching master divides, the crowning precipices are continuous for scores of miles.

A traverse of the cliff edges between Wentworth Falls and Wallerawang shows the various stages: the widening of Jamieson's Valley is proceeding; that of the high-level Kanimbla is tending to a standstill, and in the upper valley of Cox's River to the north of Wallerawang the crowning precipices are much fretted and dismantled, with a great development of caves at their bases. Caves are also found in the Permian rocks close to the stream along Piper's Flat, in a westerly direction from the town. The main valley northward contracts gently, but there is no abrupt narrowing as it passes entirely on to the hard sandstones at the head of the stream, although they have an absolute control of its widening thereabouts. Monuments are perfectly developed for many miles, and convex erosion slopes extend downwards to the base of the sandstones at the first exposures of the underlying softer rocks.

Examples could be multiplied indefinitely, but all serve to illustrate the attack along the principal line of weakness—the exposed base of the hard rocks. When the valley floors are considered, it is found that they are not confined to resistant strata or to any particular geological horizon: thus the head of Cox's River flows gently over a wide floor, and passes from Triassic sandstones to Permian clays, shales and fissile sandstones without any topographic break. Piper's Flat Creek is mainly on shales below massive conglomerates, and a similar state of affairs exists at Marangaroo and in Lithgow Valley generally. Passing down the Cox to the Kanimbla levels, streams are found flowing from Permian sandstones to granites without any marked change in topography, although much of the granite surface is decomposed and forms an undulating plain in which gorges are being carved from downstream. Apart from these instances in which streams have established their grades on weaker rocks or below zones of hardness, there are still more impressive cases. In the formation of Kanimbla Valley, Megalong Creek has cut through 300 feet of granites, while the plain of Ganbenang Creek to the north-west is eroded in similar rocks from 1,000 to 1,500 feet below the base of the Permian strata, which occur as outliers on the adjoining ridges. Turning again to the Wallerawang district, we find that Black Springs Creek, a tributary to the Cox system, has cut through the Permian sandstone and conglomerate into the underlying Devonian strata, in which it has established a mature valley 400 feet below the base of the newer series opposite its extreme outlier,—a valley which opens broadly on to those near Wallerawang carved in the newer rocks.

All of this leads to one conclusion: there are no rocks here which have been sufficiently resistant to act as a base-level of erosion while the valleys above them were being widened, and there has been no widespread "stripping" of soft rocks from underlying strata in order to undermine the sandstone capping of the tablelands and produce the level valleys. The streams have established their grades through many classes of rock, and their present state of development in the wide valleys can only have been attained through their coming close to a base-level. In the absence of rocks or horizons to prevent downcutting for any lengthy period, this base can only have been sea-level, and the wide valleys have undergone considerable uplift since their formation.

The process of valley widening under these conditions is rapid when compared with that in the hard sandstones if those have a great thickness, but it is not necessarily so from the point of absolute time. Narrow valleys with cliff sides are found in the Permian sandstones of the Endrick Valley (Shoalhaven system) cut to a depth of 500 feet, and with Tertiary basalt on their floors (Craft, 1931). In this case there was some sapping in the widening of the valleys, and these are of considerable age despite their youthful appearance. On the grounds of general resemblance there is no reason why the narrow valleys eroded in the Hawkesbury sandstones of the Macdonald, Colo, Wolgan and Grose Rivers should not be of a similar age, and the widening of valleys by differential erosion where soft underlying rocks are exposed beneath a massive capping would be looked upon as a fairly slow process. For it to approach the stage reached in the

Blue Mountains tableland a long period of stability would be required or, if the work were carried on far above the ultimate base-level, enormously resistant basement rocks would be needed in an area so close to the coast in order to resist the attack of swift invading streams, and in the process all soft material would be stripped from the valley floors. A comparison of these requirements with the existing field evidence again leads to the conclusion that the wide Blue Mountain valleys were developed with their floors much closer to sea-level than they are at present. The importance of tributaries is realized when the middle Cox or the Hunter is studied: in either case, regularly spaced tributaries have been responsible for pushing the highland masses far back from the main streams.

iii. *The Material carried by certain Highland Streams.*

There is considerable variation in the shape and size of material carried by streams—a variation that may be explained in terms of the rivers themselves and the conditions under which they flow, if it be assumed that the rocks concerned are capable of supplying large fragments for the streams to carry. Taking the question of shape first, it is found that the ultimate form assumed by pebbles is that of a surface of revolution approximating to an ellipsoid (*i.e.* with circular sections in one direction and elliptical sections in all others), although its field occurrence is governed by fairly strict rules.

David (1887, p. 40) observed rounded pebbles in the Tertiary drifts of north-western New England, while fragments of similar material in the post-Pliocene gravels are angular or subangular—conditions which prevail right along the eastern highlands of the State. Pebbles of a uniformly ellipsoidal shape are found in the older river drifts of the Nepean-Hawkesbury in the Sydney basin, on the higher terraces of the Wollondilly above its junction with the Nattai, in some of the lower terraces about the junction of the Cox and Wollondilly Rivers, above the channel of the modern Shoalhaven in the gorge at Tallong, and in the Tertiary drifts in level channels above that river. Many other examples could be quoted, but in each the shape is independent of the rock type involved, since granites, quartzites, schists and sandstones are all reduced to a common form and to a size depending largely on local circumstances: all are found where there was a tendency to pronounced deposition in former times, and there is a frequent association with red sand and clay. The basal layer of the Tertiary Shoalhaven drift may be used to illustrate the ideal conditions for shaping the pebbles.

The stratum referred to is a stream conglomerate 5 to 6 feet thick with a matrix of fine gravel or clay: it occurs over a distance of 12 miles between 1,720 and 1,760 feet above sea-level, and its even upper surface is mostly overlain by laminated clays. The pebbles in the conglomerate vary in major diameter from 3 to 12 inches, with many larger specimens up to 24 inches in some localities at the bottom of the deposit, although there is a predominance of moderate grades, about 9 inches. Some quartzite pebbles may have come from the conglomerates of the eastern divide, but the sub-angular shape of the larger fragments in those beds, and the small amount of erosion which they have suffered in the period involved, show them to be only minor factors in the supply of material, and the large stuff especially was derived from the granite and quartzite stream channels immediately above the zone of deposition. Even that which has come from the distant sources has been swept along the gentle grades of a mature landscape, and has been subjected to the same processes as the material from close at hand, the result being a uniformly ellipsoidal shape of pebbles throughout these drifts in contrast to the flattened types of the modern stream channels right from the head of the river. In the Tertiary channels, with a quantity of rock fragments moving slowly down slight gradients or along essentially horizontal surfaces with a balance of conditions favouring deposition, the nature of the motion was clearly defined. Only under rare circumstances would the velocity of the stream be sufficient to carry large stones forward over any distance without their being more or less continuously in touch with the river bed, or with material covering it; the low speed of progression would combine with friction between the fragments and the underlying material to make them rotate, and this would be all the more readily done if the river bed were screened, and the pebbles were still angular. With the disappearance of angularities the pebbles would be rolled along, gradually taking a circular section at right angles to their greatest length, as they necessarily travel broadside on to the current, and protuberances at one end would be eliminated by that extremity pointing downstream and being subjected to greater abrasion for the time being. The ellipsoidal shape of the pebbles is thus due to rotation, and its attainment must be greatly facilitated by the intermittent motion under the conditions described allowing periods of time for the weathering of edges and angles; in fact, the rounded form is intimately associated with such periods of rest, and permanent deposition is only one stage removed.

Turning to the swifter streams, the rotational factor is found to lose its importance with the increase of horizontal velocity; individual pebbles skid as they are carried forward, and the smoothing of edges does not change the general flattish shape appreciably. The heaviest material is rolled along the river bed and attains an ellipsoidal form, but if it is carried into canyons it is quickly reduced in size and broken up in swift whirls and cataracts. For a summary of active stream conditions there is no better place than Oallen ford on the Shoalhaven, a few miles above the place where the river enters the gorges. The largest pebbles (12 inches or more in diameter) are roughly ellipsoidal, but the great bulk of the material is of small size and is rather flattish, with fresh and well-rounded edges; there is no accurate sorting of the smaller stones, but all grades are mixed indiscriminately together until the top of the gravel banks is reached, where there are finer pebbles and sand. These conditions contrast with those of the ellipsoidal gravels, in which a few definite grades of pebbles predominate in each locality, and the change in size from place to place in the same horizon is limited, reminding one of Marshall's conclusions (1928) relative to the grading of beach gravels, and the persistence of certain definite sizes. The modern gravels enjoy only brief periods of rest, and the abrasion and impact to which they are subjected quickly remove any surface decomposition, and the resultant clean, polished surfaces are not readily attacked by forces of weathering. Thus the flattish form is associated with quick streams, brief periods of rest and comparatively little weathering of the fragments.

The actual mechanics of reduction have been investigated by Marshall (1928) for beach gravels of a specific rock. He recognized three principal actions: abrasion, or the rubbing of pebble against pebble; impact, or the blows of larger on smaller fragments; and grinding, or the reduction of small grains by contact with, and pressure of, pebbles of relatively large size. He states that the second of these actions is much more important than the first, although its effectiveness depends largely on the presence of coarse pebbles, and grinding is able to reduce the material supplied by impact as quickly as it is provided, while sand is not formed in quantity as the result of these actions. In addition, it is clear that among heterogeneous rocks the softer will be quickly reduced by the actions described. The coastal rivers of New South Wales support his conclusions in detail: they discharge fine material which has built up the silt flats of their lower courses, and has tended to fill their estuaries with mud (the introduction of sand into such channels as those of the lower Hunter and the Nepean-Hawkesbury is a recent matter, and is due to increased erosion of hillsides following settlement). But it is clear that conditions similar to these did not always exist, as the old gravels on the Glenbrook-Wallacia fold and the nearby Penrith-Windsor plain show. Their pebbles are ellipsoidal in form, and exceptionally large specimens attain a major diameter of 18 inches. At first sight it would appear that they were carried by more powerful streams than those existing at present, which only bring mud or hill sand, but further consideration shows the incorrectness of such a view: the uniformly ellipsoidal form of the pebbles is evidence that they were carried by slow streams under conditions which tended to favour deposition before the site of their final resting place was reached, and their continued existence was due to the fact that the streams were not powerful enough to destroy them.

At the present time, the rivers concerned are able to reduce all the material supplied to them in the normal way, and a vast quantity is poured into the gorge sections of the Cox, Kowmung and Wollondilly Rivers. In places along the first two there are long terraces of freshly broken slate and quartzite, whose extent and disposition are altered by each great flood: at other points masses of granite, generally of a cubic form with edges up to 18 inches are delivered by torrents to act as millstones and grind up the less resistant material, but only a small fraction of their number ever reaches the junction of the Cox and Wollondilly Rivers, and even where the level valley is entered, some miles above that point, the few survivors of the more resistant types have been rounded and greatly reduced in size. Unfortunately, it is not possible to estimate the number of pebbles passing into the lower Cox, but the coarse ellipsoidal gravels forming its present sides and bed are old, and are overlain by fine brown silt, many feet deep. The Cox has cut its channel in these deposits, and is not dropping new pebbles in place of those which have been removed, so the inference is that only a few new pebbles come this far, although there is movement on the channel bottom in time of flood.

Summing up these considerations, it is clear that the streams are being constantly supplied with rock waste in their canyon sections, and they have both the power and the mechanism for its comminution within short distances, so that the final product discharged is silt or mud. A comparatively recent increase in power is indicated in order to allow of this and the erosion of a new channel in the old silts and coarse gravels, while these latter indicate less favourable conditions for reduction than those existing at the present day. Further downcutting is only proceeding slowly, because the river has already established a channel fairly well suited to its mechanical requirements in times of flood.

Similar actions in the Shoalhaven River are even more striking on account of the larger rock masses supplied to it, and one outstanding inference can be drawn—that the power of a stream is to be gauged by the fineness of the material which it discharges, and any increase in the volume or power assists it greatly in breaking down the rock fragments with which it is supplied, provided that their initial size is not increased disproportionately. So far as power is concerned, it is probable that there is a critical value at which a maximum pebble size is possible in an active individual stream: if the power is reduced below this point, the size decreases owing to the inability of cutting or erosion to supply coarse material from the landscape that will give the maximum pebbles obtainable with the rock involved, even with the reduced forces of abrasion and impact. On the other hand, an increase in power beyond the critical point may supply the stream with coarser material, but the facilities for reducing it will be so increased that the resultant pebbles will be of smaller size than the maximum, and further increases in power may tend to eliminate them entirely, although in this connection much depends on the nature of the stream channel, whether it be level and smooth, or broken and obstructed.

iv. *Surface Deposits and past Climates in the Shoalhaven Valley.*

In speaking of changes in the power of a stream, the term "power" has been used with reference to a river's ability to move and reduce the rock material supplied to it. The greater proportion of such work is done in times of flood (i.e. great temporary increases in volume), and for the most part the stream is incapable of shifting any but the finest material. It follows that references made to increase of power imply the setting up of periods of heavier rainfall and more violent floods than heretofore, and not necessarily to an increase in the annual precipitation. So far as the ellipsoidal pebbles are concerned, their existence and presence argue that the streams which transported them were of some volume and power, and their form indicates the absence of relatively frequent periods of violent motion such as shape the modern stream gravels. In other words, the ellipsoidal pebbles were formed when rainfall was abundant at intervals, at least, and when violent floods were rare or altogether absent. The laminated clays and plant beds included in the Tertiary drift confirm this idea for those deposits in general, and they may represent periods of minimum storminess and stream power.

So far as the more modern stream deposits are concerned, the tendency in eastern New South Wales is towards their erosion. This is expressed in the form of gullies or channels cut in the alluvials, or in narrower terraces within the older features, the latter being marked both in the littoral belt and in the more level portions of the highlands, being distinct from recent erosion due to settlement and deforestation. In the preceding section it was concluded that there had been a recent increase in the effective power of the streams, but the origin of the alluvials presents other problems, as the deposits of the Shoalhaven Valley show.

The recent alluvials in that area are found along the flatter parts of the tributaries and of the Shoalhaven itself above the vicinity of Braidwood: they consist of 1 to 3 feet of fine drift or clay overlain by 3 to 10 feet of pebbles, with a surface covering of 1 to 3 feet of fine drift or silt. In some localities the bottom layer contains pebbles, but of a smaller size than those found above it, and the major pebble horizon cuts out as the head of each stream is approached, and the master channel is replaced by a number of more steeply graded tributary gullies or depressions. The grade at which the material was deposited varies considerably, from the approximately horizontal beds along parts of the Shoalhaven above the Braidwood district to some in the vicinity of Tallong, where local gradients may be as steep as 1 in 60, but in each place the great feature is the distinctness of the pebble horizon, whose material is uniformly fresh throughout, and which generally does not mix with the underlying or overlying deposits,

When examined in more detail, the bottom layer is found to consist of white or other light-coloured clays or sandy clays, with occasional rounded stones, and only one or two isolated instances have been observed (in the Tallong district) in which there is any trace of carbonaceous matter: the pebble beds also lack evidence of plant growth, roots or stems of trees, and only on the surface of the upper fine material is there anything approaching normal soil. The pebbles have had their edges smoothed, but they occur in various shapes and sizes from the coarse rounded material of Jembaicumbene and upper Reedy Creeks (middle valley) with diameters up to 12 or 14 inches, to those of the Marulan district or of the upper Shoalhaven, where many individuals attain a diameter of 9 inches, but few exceed it. The coarser pebbles are more rounded than the smaller, which are flattish or of irregular shape, but even near the heads of gentle local streams flowing in areas of low relief, as in the Marulan district, the rounding of edges is marked. The shape of the fragments, together with the unsorted and jumbled nature of the deposits, shows that the material was borne along by swift and turbulent streams that were greatly overloaded, and the circumstances suggest highly irregular flow such as is found in semi-arid regions.

There is also another aspect of the problem: present erosion in the old plateau landscapes is limited by the covering of trees and plants which bind the soil and prevent any but the slowest erosion except in stream channels, but when the channels were being alluviated, the drift material was derived from the landscape as a whole, and even that portion coming from areas of very low relief is fresh and relatively coarse—a state of affairs which is not reproduced under the stormy conditions of the present time. It may be inferred that the pebbles came from a surface whose vegetation was sparse, and afforded an insufficient protection from storm erosion, as the remarkable lack of vegetable matter in the drifts also appears to show. So far as time is concerned the deposits are recent, because they post-date the modern valley contour and approximate closely to modern grades, the difference rarely exceeding two or three feet on either side except where there has been gorge-cutting from the direction of the Shoalhaven.

These conditions of deposition may be correlated with the newer period of glaciation on Mt. Kosciusko, which David (1908) believes to have been of the order of 10,000 years ago, and which would be expected to introduce a cold climate into the surrounding region, with a variable rainfall of low annual value. This would militate against a continuous mantle of vegetation like that of the present day, and would favour erosion by intermittent streams incapable of shifting their full loads into the gorges. Part of the material carried after rainy periods would be deposited along the more level channels to cover the finer material dropped by preceding weaker streams, and the quick run-off would not allow of sorting, although the type of motion would make for the rounding of edges on the rock fragments. The coming of a more genial climate would explain the fineness of the top layer as there would be a more even distribution of rainfall, more plants and decreased erosion, and the gradual covering of all the drift with a deposit of hill wash in favourable positions. The dissection of the deposits has been accomplished by virtue of a general increase in stream power: this indicates a greater rainfall at some seasons, and probably an all-round increase following the disappearance of the glacial anticyclone from the southern highlands.

References.

ANDREWS, E. C., 1904.—The Geology of the New England Plateau, with special reference to the Granites of Northern New England. Pt. 1, Physiography. *Rec. Geol. Surv. N.S.W.*, vii, Part 4, 281.

————, 1910.—Geographical Unity of Eastern Australia. *Proc. Roy. Soc. N.S.W.*, xliv, 420.

BROWNE, W. R., 1928.—On some Aspects of Differential Erosion. *Proc. Roy. Soc. N.S.W.*, lxii, 273.

CRAFT, F. A., 1928.—The Physiography of the Cox River Basin. PROC. LINN. SOC. N.S.W., liii, 207.

————, 1931.—The Physiography of the Shoalhaven River Valley. iv. Nerriga. PROC. LINN. SOC. N.S.W., lvi, 412.

DAVID, T. W. E., 1887.—Geology of the Vegetable Creek Tin-mining Field. *Mem. Geol. Surv. N.S.W.*, Geology No. 1.

————, 1908.—Geological Notes on Kosciusko, with special Reference to Evidence of Glacial Action. Part ii. PROC. LINN. SOC. N.S.W., xxxiii, 657.

MARKS, E. O., 1912.—Notes on Portion of the Burdekin Valley. *Proc. Roy. Soc. Qland.*, xxiv, 93.

MARSHALL, P., 1928.—The Wearing of Beach Gravels. *Trans. N.Z. Inst.*, Vol. 58, 507.

SUSSMILCH, C. A., 1931.—Physiography of the Bathurst District of New South Wales. *Proc. Roy. Soc. N.S.W.*, lxv, 80.